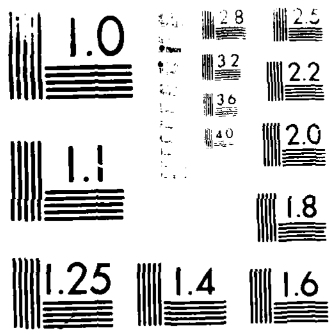
AD-A172 073 AN ANALYSIS OF SUPPLEMENTAL INFORMATION IN CONTOUR TO GRID PROCESSING(U) DEFENSE MAPPING AGENCY WASHINGTON DC R B EDELEN AUG 86 1/1

UNCLASSIFIED F/G 8/2 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

UNCLASSIFIED

SECURITY CLAS

AD-A172 073

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION | Unclassi |
| 1b. RESTRICTIVE MARKINGS | n/a |
| 2a. SECURITY CLASSIFICATION AUTHORITY | n/a |
| 3. DISTRIBUTION/AVAILABILITY OF REPORT | Approved for public release; Distribution is unlimited |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | n/a |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | n/a |
| 5. MONITORING ORGANIZATION REPORT NUMBER(S) | n/a |
| 6a. NAME OF PERFORMING ORGANIZATION | Defense Mapping Agency |
| 6b. OFFICE SYMBOL (If applicable) | PAO |
| 7a. NAME OF MONITORING ORGANIZATION | n/a |
| 6c. ADDRESS (City, State, and ZIP Code) | Washington, D.C. 20305-3000 |
| 7b. ADDRESS (City, State, and ZIP Code) | n/a |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION | DMA Hydrographic/Topographic Ctr |
| 8b. OFFICE SYMBOL (If applicable) | DPT |
| 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER | n/a |
| 8c. ADDRESS (City, State, and ZIP Code) | Washington, D.C. 20315-0030 |

10. SOURCE OF FUNDING NUMBERS

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT ACCESSION N |
|---|---|---|---|
| n/a | n/a | n/a | n/a |

11. TITLE (Include Security Classification)

An Analysis of Supplemental Information in Contour to Grid Processing

12. PERSONAL AUTHOR(S)

Edelen, Robert B.

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| final | FROM ________ TO ________ | 1986 August | 9 |

16. SUPPLEMENTARY NOTATION

1986 ASPRS/ACSM Fall Convention
28 Sep - 3 Oct 1986 Anchorage, Alaska

17. COSATI CODES

| FIELD | GROUP | SUB-GROUP |
|---|---|---|
| 08 | | |
| | | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Terrain Elevation Matrix
linear interpolation
slope transition

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

For more than 20 years, the Defense Mapping Agency (DMA) has processed digitized contour from map sources to produce regularly spaced matrices of elevation data. A wide variety techniques and algorithms may be employed to produced thes gridded data sets, with each algorithm creating artifacts in the data that reflect the gridding approach used. In an effort to improve data quality and accuracy, and to increase throughput in the productio elevation matrices, DMA has expended considerable resources for the development and eval tion of new gridding techniques and algorithms. The algorithms reviewed have employed; planar, linear and weighted average interpolation techniques which offer at best a linea interpolation between features; (2) surface fitting algorithms designed to approximate t earths's surface between features with curve fitting techniques; and (3) combinations of linear interpolation algorithms followed by filtering techniques to produce a smooth, co tinuous surface between features. Many of the gridding approaches evaluated are the res of attempts to reduce or eliminate the need for inclusion of supplemental geomorphic in

| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT | 21. ABSTRACT SECURITY CLASSIFICATION |
|---|---|
| ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS | UNCLASSIFIED |

| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE (Include Area Code) | 22c. OFFICE SYMBOL |
|---|---|---|
| Robert B. Edelen | 202-227-2608 | DPT |

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PA
UNCLASSIFIED



86 9 18 0

Item 19. (Continuation)

mation such as drain lines and ridge lines between contours. The elimination of this type of data has potentially significant cost saving benefits, in that a major predigital compilation effort to prepare the supplemental information for digitizing would be minimized. However, in cases evaluated at DMA, the elimination or reduction of supplemental data has only served to degrade the quality and accuracy of the final elevation matrix.

This paper discusses two approaches to contour-to-grid interpolation investigated at DMA and the implications of including or omitting supplemental elevation information. Discussion includes the use of supplemental data to ensure continuity at data set boundaries and the elimination of plateauing created by linear interpolation techniques. Additionally, accuracy and quality as well as surface texture appearance issues are addressed with regard to surface fitting algorithms, stressing the behavior of interpolation algorithms around slope changes. The paper concludes with a discussion of the outstanding issues which must be resolved for more efficient contour-to-grid processing, and the ongoing activities at DMA to address these issues.

# AN ANALYSIS OF SUPPLEMENTAL INFORMATION IN CONTOUR TO GRID PROCESSING

ROBERT B. EDELEN
UNITED STATES DEFENSE MAPPING AGENCY, WASHINGTON, D.C., 20305

## ABSTRACT

For more than 20 years, the Defense Mapping Agency (DMA) has processed digitized contour data from map sources to produce regularly spaced matrices of elevation data. A wide variety of techniques and algorithms may be employed to produce these gridded data sets, with each algorithm creating artifacts in the data that reflect the gridding approach used. In an effort to improve data quality and accuracy, and to increase throughput in the production of elevation matrices, DMA has expended considerable resources for the development and evaluation of new gridding techniques and algorithms. The algorithms reviewed have employed: (1) planar, linear and weighted average interpolation techniques which offer at best a linear interpolation between features; (2) surface fitting algorithms designed to approximate the earth's surface between features with curve fitting techniques; and (3) combinations of linear interpolation algorithms followed by filtering techniques to produce a smooth, continuous surface between features. Many of the gridding approaches evaluated are the results of attempts to reduce or eliminate the need for inclusion of supplemental geomorphic information such as drain lines and ridge lines between contours. The elimination of this type of data has potentially significant cost saving benefits, in that a major predigital compilation effort to prepare the supplemental information for digitizing would be minimized. However, in cases evaluated at DMA, the elimination or reduction of supplemental data has only served to degrade the quality and accuracy of the final elevation matrix.

This paper discusses two approaches to contour-to-grid interpolation investigated at DMA and the implications of including or omitting supplemental elevation information. Discussion includes the use of supplemental data to ensure continuity at data set boundaries and the elimination of plateauing created by linear interpolation techniques. Additionally, accuracy and quality as well as surface texture appearance issues are addressed with regard to surface fitting algorithms, stressing the behavior of interpolation algorithms around slope changes. The paper concludes with a discussion of the outstanding issues which must be resolved for more efficient contour-to-grid processing, and the ongoing activities at DMA to address these issues.

## INTRODUCTION

The digital terrain elevation matrix is a highly desirable form for storing and processing elevation data. These matrices take the form of regularly spaced elevations on the Earth's surface, which may be represented in a variety of coordinate systems, data spacings and data set sizes. Once the data have been produced in this form, it can be manipulated to produce a variety of useful products such as relief models and perspective views of the earth's surface, simulated scenes to support flight and ground simulation, or to provide planning information for cross country movement, quantity determination, mining and forestry

feasibility, and civil planning. In each case, the use of the digital terrain elevation matrix may greatly reduce costs, manpower and time to achieve the desired results. A popular technique for producing the digital terrain elevation matrix is to digitize contours from existing map sources, perform a coordinate transformation on the digitized data, and then process the data through an interpolation algorithm to produce a matrix of elevations in the desired coordinate system and spacing. Algorithms developed to produce interpolated matrices may be grouped into two generic classes. The first class of algorithms employ planar, weighted average, or steepest slope types of techniques, whose results are characterized by a linear interpolation between features, flattening of valleys, tops and ridges, and angular transition at areas of slope change (see Figure 1).

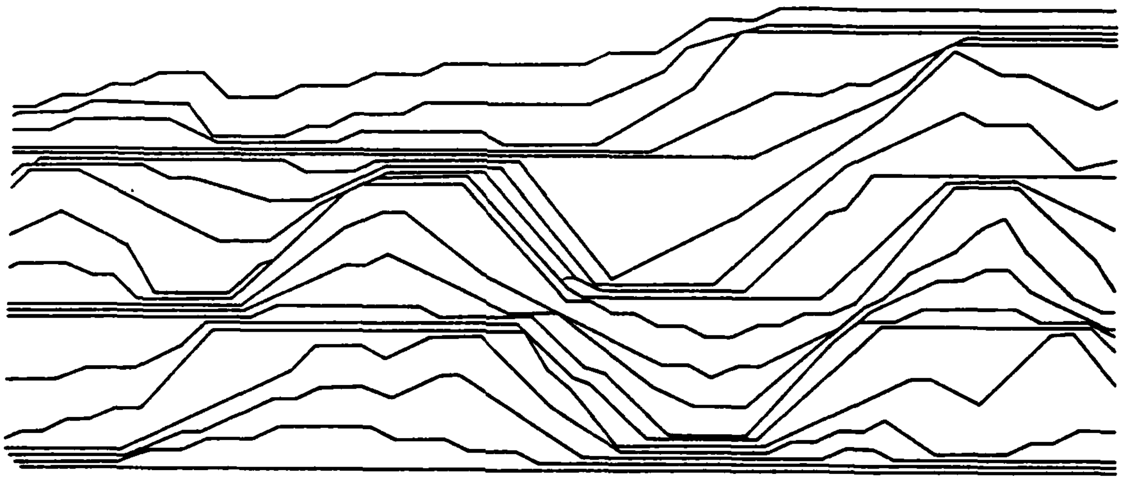


Figure 1. Profiles of Elevations Generated by Linear Interpolation

These algorithms were among the first to be used to create elevation matrices because they required relatively modest processing demands and could be executed on earlier, slower CPUs (Mays, Noma and Aumen, 1965). The second class of algorithm employs spline fitting, biquadratic, or polynomial types of techniques to produce a smooth continuous surface between input features. These techniques offer considerable improvement over linear interpolation algorithms in that valleys, tops and ridges are rounded, and a smooth transition exists at areas of sharp slope change (Junkins and Jancaitis 1971) (see Figure 2).

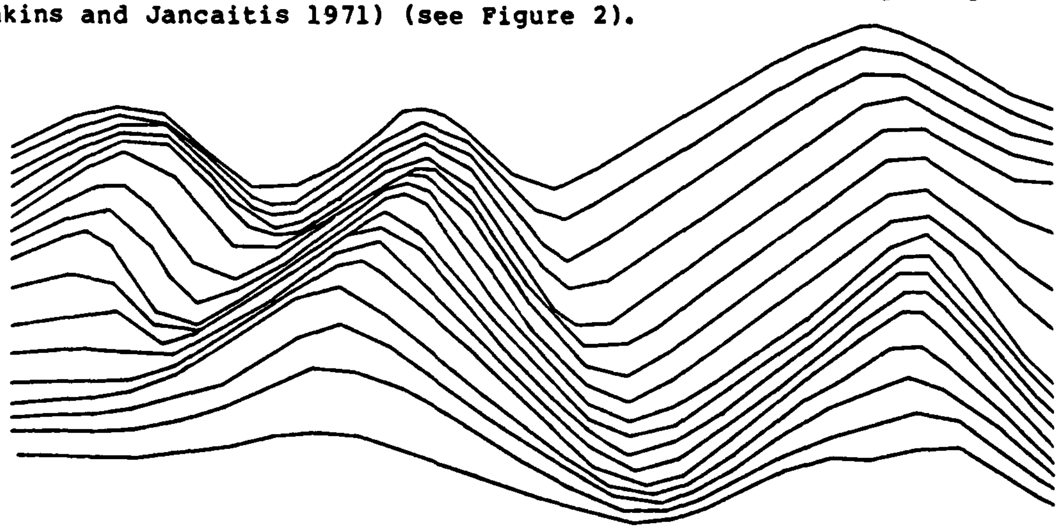


Figure 2. Profile Plot of Elevations Generated by Curve Fitting Interpolation

For the most part, any interpolation technique employed will provide acceptable results in areas of constant or near constant slope. However, regardless of the interpolation technique, measures must be taken in areas of surface transition to insure an accurate depiction of the terrain.

## LINEAR INTERPOLATION AT AREAS OF SLOPE CHANGE

### Advantages and Disadvantages of Linear Interpolation techniques

Advantages. Linear interpolation techniques offer several advantages over curve fitting techniques. First, linear techniques will always constrain the interpolated elevations to remain between or at the elevations of the input features, regardless of the severity of any slope change or change in elevation of input features (e.g. change in contour interval). This feature insures that the accuracy of the resulting elevation matrix falls within the contour interval of the digitized manuscript. Additionally, because the interpolation is linear, naturally flat areas are interpolated flat with no noise introduced. This is particularly significant where lakes, plateaus, and glacial flattening occur. In these areas, no particular precautions are required because the lake, plateau or glacial plain may be treated as contours, resulting in acceptable flattening by the linear interpolation algorithm. As previously stated, another advantage of linear interpolation is efficiency. The planar interpolation employed at DMA requires approximately 30 minutes of wall clock time on a VAX 11/780 to produce a matrix of 1,442,000 elevations.

Disadvantages. The disadvantages of linear interpolation occur primarily at tops, ridges, valleys and other areas of slope change where flattening and angular transition are introduced. The impact of these characteristics can be reduced by predigital enhancement of the digitizing manuscripts as will be discussed in the next section.

### Linear Interpolation at Areas of Slope Change

Data Set Boundaries. The general appearance of matrix data created by a linear interpolation at a data set boundary is acceptable until two adjacent data sets are compared side by side. This type of comparison will most often reveal discrepancies resulting from contours and other features which come close, but do not actually cross or contact the data set boundary (see Figure 3.A). These features have contributed to the interpolation of elevations on one data set, but do not influence the other. The result is an obvious break in continuity between data sets as depicted in a profile cross section in Figure 3.B. The approach taken at DMA to resolve this problem is to enhance the boundary information of each data set with the addition of identical supplementary elevations to the border, and to include the supplementary elevations in the linear interpolation of the boundary (see Figure 3.C). These elevations take into account any features which approach the boundary and provide sufficient information to achieve continuity (see Figure 3.D). Another approach is the digitization of data which extends far enough beyond the border to consider all features which should influence the boundary interpolation. This information is then used in the interpolation providing satisfactory results at data set boundaries.

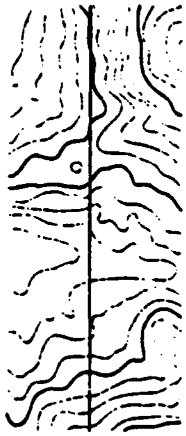


Figure 3.A

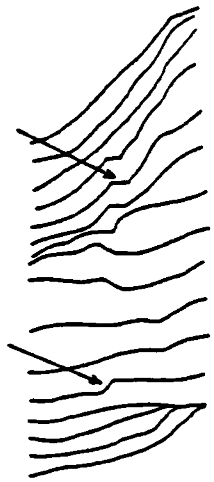


Figure 3.B

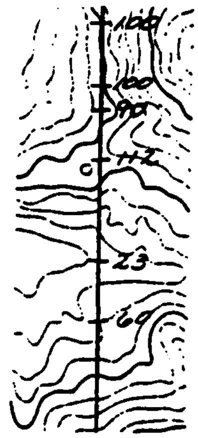


Figure 3.C

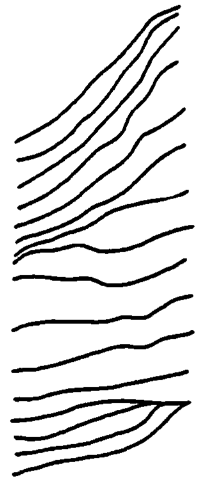


Figure 3.D

Tops, Ridges and Valleys. In areas of tops, ridges and valleys, linear interpolation techniques create unnatural flattening which, when reflected in perspective scenes, simulations, relief maps, shaded relief images or other visual products, tend to distort the image and detract from it's overall usefulness. This flattening is further enhanced in areas where the drain/ridge pattern is dense and the slope is gradual (see Figure 4.A). In this case, the interpolated elevation matrix takes on the appearance of a staircase. Contours which reflect the tight drain/ridge pattern are completely flattened and the transition of elevations from one contour interval to the other occurs in a relatively short space between wide bands of flat elevations (see Figure 4.B). To correct for the flattening effect of the linear interpolation, DMA enhances tops, ridges and valleys with the addition of drain and ridge lines. These enhancements are made in a predigital compilation phase or interactively during the digitizing process, where lines corresponding to the centers of ridges and drains are compiled, digitized and incorporated into the interpolation. Originally, these drain and ridge lines were segmented with each segment assigned an elevation, and the segments were treated as short contours in the interpolation phase. However, as of more recent, drain and ridge lines are compiled as a single line and processed through an algorithm, where elevations along the drain and ridge lines are interpolated linearly between contours. Additional elevations may be added along drain and ridge lines at junctions, or at changes in slope for improved accuracy. This approach eliminates flattening along most valleys and ridges, thereby providing a more realistic presentation of the terrain surface (see Figure 4.C). To eliminate flattening in tops, a similar technique is used. A ridge line is added at the center line of the top and an elevation taken from larger scale maps (or interpolation) is assigned to the highest point, prior to linear interpolation of elevations along the ridge. When tops are too small for interpolation of ridge lines, a single spot elevation is used.

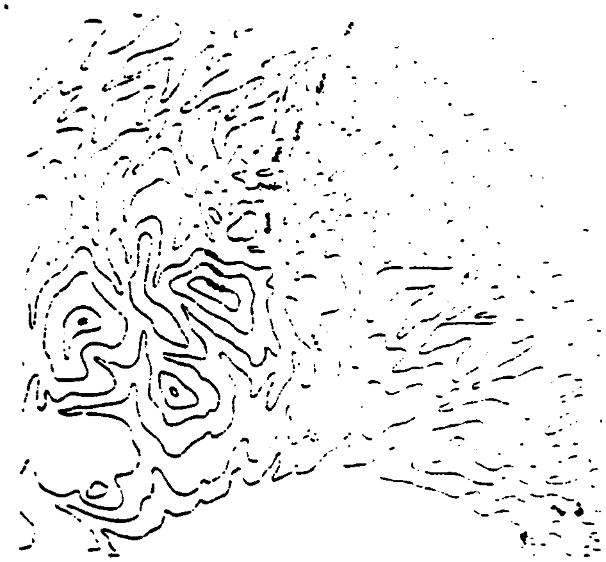


Figure 4.A

Figure 4.B

Figure 4.C

Slope Transition. In areas of transition from a steep slope to a more gradual slope or a gradual to steep slope, the linear interpolation algorithms create sharp angularities at the features where the transition occurs. These angularities are apparent throughout most elevation matrices created through linear interpolation. Two approaches may be employed to reduce angularity. The first is to interpolate supplemental contours near the area of transition, breaking the angularity into several less noticeable angles. The second is to filter the elevation matrix. As a rule, neither of these techniques are employed at DMA. The first is too time consuming and the second, although useful for some applications, may tend to degrade the overall accuracy of the elevation matrix.

CURVE FITTING INTERPOLATION AT AREAS OF SLOPE CHANGE

Advantages and Disadvantages of Curve Fitting Techniques

Advantages. Curve fitting techniques have become increasingly popular as more powerful computers become available. Curve fitting algorithms

can now compete with linear interpolation algorithms with regard to processing efficiency, and offer greatly improved results from a representation standpoint over linear techniques. Because curve fitting algorithms tend to round up tops and ridges and round down valleys, considerable manhour resources can be saved in predigital compilation. Curve fitting algorithms present a smooth transition in areas of slope change, tops, ridges and valleys, regardless of the angle of change or size of feature, and removes the angular, jagged texture presented by linear techniques.

Disadvantages. Although curve fitting techniques present a smoother appearing surface in areas of tops, ridges, valleys and slope change, there is a tendency to overshoot tops and ridges and undershoot valleys where the slope transition is sharp. This overshooting and undershooting extends to any area of steep transition of slope, potentially introducing false tops and depressions in the resulting elevation matrix, allowing the range of elevations to float beyond the constraint of the contour interval creating potential accuracy problems.

*Curve Fitting Interpolation at Areas of Slope Change*

Data Set Boundaries. As with linear interpolation, curve fitting algorithms will require special treatment at data set boundaries. Depending upon the algorithm used, a simple linear interpolation of boundary points may not be acceptable. If the number of points required to initialize the curve fitting algorithm exceed one row or column at the boundary, then an approach which extends the area to be interpolated beyond the border may be employed. As with linear interpolation the digitized information will extend beyond the boundary with sufficient margin to insure that the curve fitting algorithm approaches the border with the proper slope to avoid gross boundary mismatches. Regardless of the technique employed, some minor elevation adjustment at data set boundaries may still be required to insure an identical match of elevations.

Tops and Ridges. A major benefit of curve fitting algorithms is derived at tops and ridges. Where linear interpolation tends to flatten tops and ridges, curve fitting algorithms round them up, providing a more realistic and accurate depiction of the terrain surface with little or no enhancement of the digitizing manuscript required. However where tops and ridges plateau or in any area where a sharp incline stops abruptly, curve fitting algorithms tend to overshoot (see figure 5), introducing false peaks in the data which may be in error by up to several contour intervals.

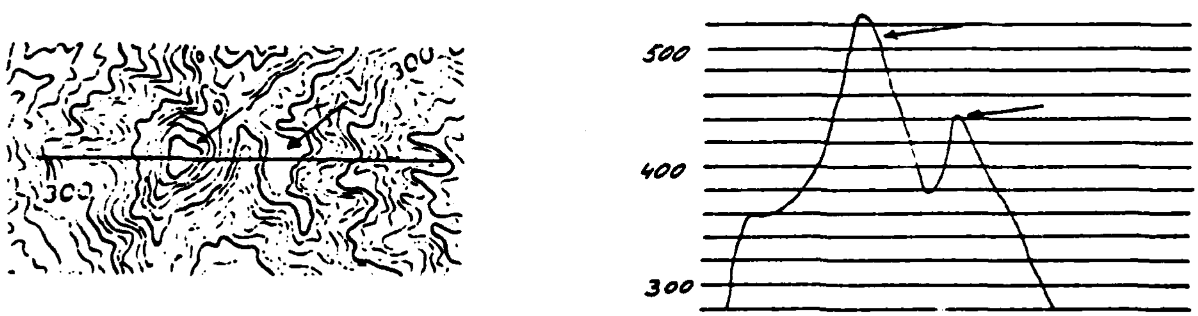
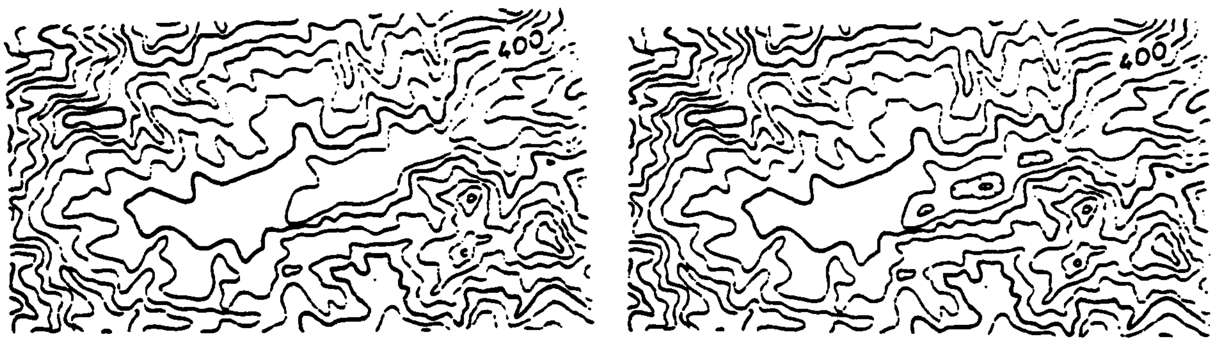



Figure 5. Overshoot of contour interval

One approach to correcting this error is the addition of supplemental contours in a predigital compilation phase to influence the trajectory of the curve, eliminating the over shoot. Another approach constrains the algorithm from extending the curve beyond one contour interval unless the next higher contour exists. This approach offers the greatest potential, both from an efficiency and accuracy standpoint. However, techniques must be devised to effectively accommodate supplemental contours, changing contours, lakes and other supplementary information for this technique to work correctly.

Valleys and lakes. In areas of valleys and lakes, many problems with curve fitting algorithms exist. Although these algorithms round down valleys and seemingly eliminate the need for predigital enhancement, they introduce anomalies that are not easily corrected. First, the problem of undershoot exists for valleys the same way overshoot exists for tops. In any area such as glacial plains where there is a sharp transition from steep to gradual slope, the problem of undershoot will occur resulting in false valleys with vertical errors of up to several contour intervals. Another problem arises because curve fitting algorithms do not conform to rules which specify that valleys (unless depressions) always flow down hill. Because elevations interpolated by curve fitting algorithms conform to contours which define valleys, the interpolated elevations fluctuate vertically depending upon the steepness of slope and separation of contours across valleys. The results are numerous false depressions introduced in valleys which should flow continuously down hill (see Figure 6).



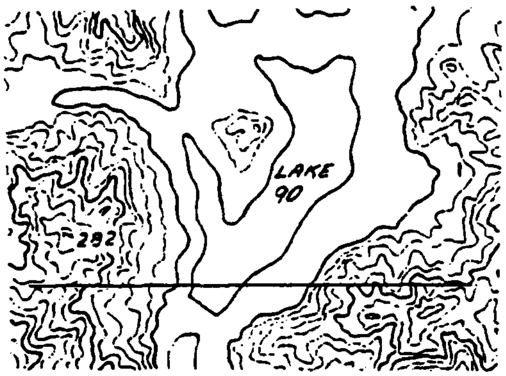

Original Contours

Introduced Depressions

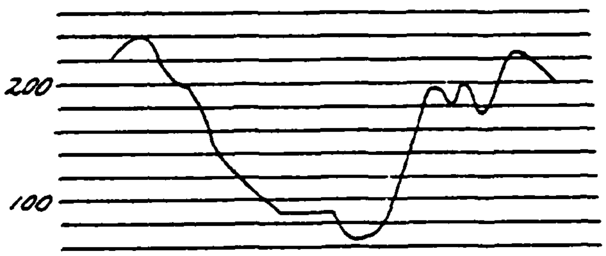
Figure 6. False Depressions Resulting from Undershoot

The addition of drain lines as an aid in defining the focal point of a valley offers little help in resolving valley problems, and in some cases only compounds the problem. Because most curve fitting algorithms are continuous, they tend to fit the curve to drains as they relate to surrounding contours. That is, the curve will most often pass through the drain, placing lower elevations on one side of the drain or the other, but not often using the drain line as the lowest possible point. Again, the results are numerous false depressions in the interpolated matrix. Similar problems occur where water bodies are present in the elevation

matrix. Assuming that a preprocess occurs which generates the surface of lakes and other water bodies and that water surface elevations are not allowed to fluctuate during the gridding process, the problem of under shoot may generate elevations adjacent to the water which are less than the elevation of the water body. Again this problem surfaces where a transition exists between sharp and gradual slopes. The result places the water surface higher than the surrounding terrain, creating an unnatural plateauing effect with the water body at the top of the plateau. Figure 7 shows the digitized data and a cross section with the resulting lake isolation.




Digitized Data




Profile Of Cross Section

Figure 7. Lake Isolation Resulting From Undershoot

As with the overshoot problem, software exists to constrain undershoot to within the contour interval (Zoraster, 1984). However, additional development is required to constrain curve fitting algorithms to elevations of lakes, drains and supplemental contours.

## CURRENT STATUS OF CONTOUR TO GRID PROCESSING AT DMA

### Current Production

The software used at DMA for the production of elevation matrices from digitized contours employs a planar type interpolation technique, where three known elevations are used to form a plane from which elevations are extracted. As previously stated, this approach provides, at best, a linear interpolation between digitized features. To augment the contours, DMA enhances the digitizing manuscript (or the digitized file) with the addition of drain/ridge lines, spot heights, supplemental contours, lake and other water bodies, and supplemental elevations at the data set boundaries. This approach provides acceptable results with vertical accuracies within the contour interval of the original map sheet. The drawbacks associated with this approach, as previously stated are the time required for the predigital enhancement effort (approximately 80 hours per map sheet), and the angularity of the matrix at intersections with input contours and supplemental data.

### Developmental Efforts

Since 1980, DMA has pursued efforts to improve the results of contour to grid processing and reduce the time required for predigital enhancement. To achieve these goals, DMA has awarded several R&D contracts for the development of algorithms which, first, implement a weighted linear interpolation to initialize an elevation matrix, and second, filter the elevation matrix creating a smooth continuous surface between contours

and supplemental information. These developmental efforts have so far resulted in software that performs the grid initialization and flags matrix points near contours to restrict filtering of elevations that coincide with input data. Additionally, lake and other water bodies are interpolated and flagged to prevent filtering. The filtering software is implemented through numbers of passes, with each successive pass of the filter relaxing the terrain surface slightly more than the previous pass. Limits may be imposed which constrain the amount of curvature to within the contour interval. The results are similar to other curve fitting algorithms, but with overshoot and undershoot controlled. Additional work is required to treat valley lines as discontinuities in the filtering operation and to constrain curving based on continuously changing parameters rather than discrete contour intervals.

## CONCLUSION

Curve fitting techniques applied to the construction of digital elevation matrices from digitized contours offer significant benefits over linear interpolation techniques. Most benefits lie in their ability to fit a smooth surface between input points, rounding off tops and valleys, presenting a more realistic depiction of the terrain, and eliminating the angular, jagged appearance generated by linear interpolation techniques. Disadvantages of curve fitting techniques surface at areas of sharp transition from steep to gradual slope and in valleys where overshoot and undershoot tend to distort the generated surface with unnatural tops and depressions. Additional work to constrain overshoot and undershoot to lines defining local minima and maxima (drain lines, ridge lines, spot heights, water bodies and supplementary contours) will greatly improve the depiction and accuracy of elevation matrices.

## REFERENCES

Mays, R. R., Aumen, W. C. and Noma, A. A., "Digitizing Graphic Data at the Army Map Service", Proceedings of the 1965 ASP-ACSM Convention

Junkins, J. and Jancaitis, J. R. "Mathematical Terrain Modeling", U. S. Army Engineering Topographic Laboratory Report, 1971

Zoraster, S, "Report on the Development of a Special USGS Version of Contour to Grid Software", 1984

END

DTIC

11-86